

Cone beam computed tomography in paediatric dentistry: overview of recent literature

J. K. M. Aps

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Abstract

Background The use of cone beam computed tomography (CBCT) in paediatric dentistry has been mentioned in numerous publications and case reports. The indications for the use of CBCT in paediatric dentistry, however, have not yet been properly addressed. On the other hand, the three basic principles of radiation protection (justification, limitation and optimisation) should suffice.

Review A review of the current literature was used to assess the indications and contra-indications for the use of CBCT in paediatric dentistry. Paramount is the fact that CBCT generates a higher effective dose to the tissues than traditional dental radiographic exposures do. The effective radiation dose should not be underestimated, especially not in children, who are much more susceptible to stochastic biological effects. The thyroid gland in particular should be kept out of the primary beam as much as possible.

Conclusion As with any other radiographical technique, routine use of CBCT is not acceptable clinical practice. CBCT certainly has a place in paediatric dentistry, but its use must be justified on a patient case individual basis.

Keywords Cone beam computed tomography · Paediatric dentistry · Diagnosis · Safety

Background

The frequency of dental radiographs is very high compared to other medical exposures and some patients undergo

several investigations in a short period of time, especially for instance, in cases in dento-alveolar trauma. Some people believe a bit of radiation does not harm (the so-called hormesis theory), nonetheless, ionizing radiation is definitely not considered 100 % harmless by the majority of radiation physicists and local and international advisory bodies. Dental radiographs are taken at fairly low kilovoltages, which implies that the risks are rather unpredictable (Wall et al. 2006).

The accumulative effect of ionizing radiation should always be considered. Epidemiological studies have not provided clear evidence of radiobiological effects of low energy X-rays. Judgments based on extrapolation from higher doses are made in the light of findings from cellular studies and experiments with animals. The latter studies are not always conclusive when it comes to assessing the cause-effect relationship between radiation and induced carcinogenesis. All international organisations, such as the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Radiological Protection Board (NRPB), now called the UK's Radiation Protection Division of the Health Protection Agency and the National Council on Radiation Protection and Measurement, USA (NCRP), overseeing the risks of ionizing radiation, agree that for low energy radiation, stochastic effects (there is no threshold dose for these effects to appear) are at all times a potential risk.

The so-called linear no threshold (LNT) model is used to assess the risks of low energy ionizing radiation, with the knowledge that it will sometimes overestimate or underestimate a risk. Intra-oral dental radiographs are considered as of negligible risk, as the risks of developing a fatal tumour are well below one in a million. However, it is also true that sex, age and individual susceptibility to cancer

J. K. M. Aps (✉)
Department of Paediatric Dentistry, University of Washington,
Magnusson Park, 6222NE 74th Street, Seattle, WA 98115, USA
e-mail: apsj@uw.edu

have to be taken into account. The ultimate conclusion is that the LNT model provides sufficiently reliable risk assessment to ensure that patients are being adequately protected from medical exposures that are either unjustified or not fully optimised (Wall et al. 2006).

Basic principles of radiation protection

With regard to children, a dental practitioner should be even more alert not to expose any young growing individual to “unnecessary” radiation. Economic purposes should never be a reason for subjecting patients to ionizing radiation. This brings us to the three basic principles of radiation protection. Firstly there is the “justification principle”, which means that taking radiographs is only indicated if there is no other means of obtaining the necessary information. It also says that if the patient cannot cope with the procedure, no radiographs should be taken (e.g. do not proceed if a child cannot stand still long enough during a panoramic radiograph taking). Secondly there is the “limitation principle”, which says that practitioners should always try to keep the radiation dose to a patient as low as reasonably achievable (ALARA). Thirdly there is the “optimisation principle” which states that any practitioner should always try to obtain the best diagnostic images possible, with both previous principles in mind.

Radiation dose

In the literature, unfortunately, it is not always clear what is meant by radiation dose, accordingly some explanation is needed. The “absorbed radiation dose” (abbreviated as D) is the measure of the amount of energy absorbed from the radiation beam per unit mass of tissue; the unit is the Gray. It used to be measured in RAD (which stands for radiation absorbed dose) and 1 Gray equals 100 RADs. The “equivalent dose” (abbreviated as H) is a measure which allows the different radiobiological effectiveness of different types of radiation to be taken into account. A radiation-weighting factor (abbreviated as WR) represents the biological effects of each type of radiation. For X-rays this weighting factor equals “one”, while for alpha particles it equals “20”. The figure quantifies the severity of the effect of the type of radiation; the unit of equivalent dose is the Sievert. For dentistry often milli- or microSieverts are used to express equivalent doses. The old unit was the REM (which stood for Röntgen equivalent man) and 1 Sievert equals 100 REMs. As the radiation-weighting factor for X-rays is “one”, the absorbed radiation dose and the equivalent dose are equal. Hence, the confusion in literature between Grays and Sieverts and between absorbed and equivalent dose.

The “effective dose” (abbreviated as E) allows doses from different investigations of different parts of the body to be compared. The effective dose for X-rays equals the equivalent dose (as $WR = 1$) and therefore is expressed in Sievert units as well. The doses are converted into an equivalent whole body dose. This is necessary to distinguish the sensitivity of several tissues to ionizing radiation. Therefore, a tissue-weighting factor (abbreviated as WT) has been introduced for radiosensitive organs and tissues. The sum of all tissue weighting factors equals “one”, the tissue weighting factor for the whole body. The more radiosensitive a tissue, the higher the tissue-weighting factor. These factors have been put forward by the ICRP and Table 1 shows all the different tissue weighting factors, which are used to calculate the effective radiation dose (Hendee et al. 2002; Graham et al. 2004; Whaites 2007a; Mettler and Upton 2008). De Vos et al. (2009) stressed that when radiation is discussed in the literature and reported, it has to be specified what is exactly meant. They suggest dose should be interpreted as effective dose, when dealing with clinical situations where patients are exposed to ionizing radiation, which is in accordance with the ICRP guidelines. Absorbed dose will not suffice, as this does not take into account the different biological tissues and their inherent radiation sensitivity.

Table 2 provides an overview of some medical and dental examinations and their respective effective radiation dose (Whaites 2007a). To put these figures into perspective it is interesting to know that the annual natural background radiation dose in Europe is about 2,500 μ Sv and in the USA it is 3,600 μ Sv. Depending on the altitude (the higher

Table 1 ICRP tissue weighting factors as agreed upon in 2006 (Whaites 2007a; Mettler and Upton 2008)

Tissue	Effective dose weighting factor
Breast	0.12
Red bone marrow	0.12
Lung	0.12
Colon	0.12
Stomach	0.12
Gonads	0.08
Thyroid	0.04
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remainder	0.12
Total	1.00

Table 2 The effective dose of different medical and dental examinations (Whaites 2007a)

Type of X-ray examination	Effective dose in microSieverts
CT chest	8,000
CT skull	2,000
Lateral skull radiograph	10
Frontal skull radiograph	30
Lateral chest radiograph	40
Frontal chest radiograph	20
Dental panoramic radiograph	24
Dental peri-apical radiograph	
50 kV, circular collimation, D-speed film	8
70 kV, rectangular collimation, F-speed film or digital receptor	1
Dental cone beam CT	5–300 ^a

^a Estimate added by the author of this paper, gathered from several publications on CBCT equipment

the more natural background radiation) and a person's activities (e.g. a transatlantic flight will add additional radiation) the natural background radiation can vary substantially (Hendee et al. 2002; Graham et al. 2004; Whaites 2007a; Mettler and Upton 2008). As a consequence it is necessary to always present exposure to ionizing radiation, otherwise some will propagate and support the hormesis theory (some radiation does not harm us), as mentioned above.

In Table 3 an overview of sources of background radiation is provided (Hendee et al. 2002; Graham et al. 2004; Whaites 2007a; Mettler and Upton 2008). It is clear that one peri-apical radiograph, taken at ideal conditions, represents only a very small portion of extra radiation for a patient, in contrast to, for example, a CT investigation of the skull. The latter almost equals an extra year of background radiation. The percentage of medical exposures, however, has in the last two to three decades increased dramatically due to several reasons. First there is the abundant use of CT investigations, which, if justified, outweigh the health risks for a patient; nevertheless their use has increased. Secondly there is the increased use of medical imaging for medico-legal purposes. The latter has, in certain areas of the world, had a large impact on the exposure of the public to ionizing radiation and could have a significant contribution.

With regard to dental medical imaging, the increasing use of cone beam CT will probably, and perhaps unfortunately, have a similar impact. The effective dose, given for cone beam computed tomography (CBCT), in Table 2 is rather vague because there is no standardisation of kilovoltage or milli-Ampères, and also the field of view (the size of the scan) can vary substantially. A small field of

Table 3 An overview of all types of background radiation and their effective dose, for Europe

Radiation source	Average yearly dose for an adult person (in μSv)
Natural background radiation	
Cosmic radiation	300
Earth's crust radiation	400
Nutrition	370
Radon and decay products	700
Artificial background radiation	
Fallout (~Chernobyl, Fukushima, etc.)	10
Radio-active waste	2
Medical and dental diagnostic radiation	250
Occupational exposure (e.g. aviation, nuclear plants, etc.)	9

view results in a lower dose, but the resolution is proportionate to the dose, meaning that what can be "gained" in dose reduction, by reducing the size of the scan, can easily be lost by increasing the resolution. Moreover, because of the wide variety of devices on the market it is not possible to determine a concise figure for effective dose.

In a 2006 publication by Wörtche et al. (2006) and in another article providing information on 14 different machines published in 2012 by Pauwels et al. (2012), this issue is addressed very clearly. These investigators, as well as Ahmad et al. (2012) also emphasised the relativity of effective dose comparisons. That is very disturbing as it implies there is no clear cut answer to what biological effect the effective dose has on a young individual. It is without any doubt correct to say that CBCT results in a lower effective dose than medical CT (also referred to as multislice CT or conventional CT). The latter is often used in publications to support its use in dentistry. However, with regard to a bitewing for example, the difference may be substantial, especially if the field of view is relatively large (e.g. 8×8 cm) and the resolution is high (e.g. 200 microns).

In Table 4 the estimated risks per radiographic examination for an adult person to develop a fatal cancer are shown (Whaites 2007b). It is obvious that several examinations hold serious risks, but these are justifiable if the benefit outweighs the risk. It is clear that using radiographs as a screening tool, to 'fish' for accidental findings, is unacceptable clinical practice. Table 5 shows the multiplication factors for the risk, with regard to the age of the patient (Whaites 2007b). Children are more vulnerable to ionizing radiation and therefore at higher risk because firstly their tissues are growing at a faster rate and are

Table 4 Some medical ionizing radiation exposures and their estimated risk for a fatal cancer to develop in an adult person (Whaites 2007b)

Radio-diagnostic examination	Estimated risk for a fatal cancer to develop in an adult patient
CT skull	1/10,000
CT chest	1/2,500
Frontal chest radiograph	1/1,000,000
Lateral skull radiograph	1/2,000,000
Frontal skull radiograph	1/670,000
Dental panoramic radiograph	1/1,000,000
2 bitewings or peri-apical radiographs	
50 kV, circular collimation, D-speed film	1/2,000,000
70 kV, rectangular collimation, F-speed film or digital detector	1/20,000,000

Table 5 Age correlated multiplication factors for the estimation of a fatal cancer developing from exposure to ionizing radiation (Whaites 2007b)

Age category	Multiplication factor
<10 years	3
10–20 years	2
20–30 years	1.5
30–50 years	0.5
50–80 years	0.3
>80 years	0 (negligible)

therefore more vulnerable to DNA damage and other changes; secondly because the chances of a tumour developing after being exposed to a panoramic radiograph are much higher in a child than in a 50 year old for instance, as the time allowed for the tumour to develop is much longer as the child has statistically and realistically more years to live after the exposure.

Biological effects of ionizing radiation

Ionizing radiation holds the potential to cause biological effects. These are categorised as either “deterministic or stochastic effects”. “Deterministic effects” will occur when high-energy ionizing radiation is involved. It can cause damage to tissues, such as reddening and cataract formation. The severity of these effects depends on the radiation dose and as such a certain threshold dose exists which must be exceeded in order to have the effect. Accidents such as those at Chernobyl and Fukushima and the atomic bombing of Nagasaki and Hiroshima have provided the necessary information regarding these threshold doses (Hendee et al. 2002; Graham et al. 2004; Whaites 2007b; Mettler and Upton 2008).

The energies used for dental exposures are far below these doses, and as a consequence deterministic effects will never happen. However, stochastic, or probabilistic, effects involve low energy ionizing radiation, such as the ones used in dentistry. These effects are unpredictable, as there is no such threshold dose that has to be exceeded to cause an effect such as leukaemia or a tumour development. The development of so-called stochastic effects is based on probability or the laws of chance, therefore one should always take precautions when exposing patients to ionizing radiation. As a consequence every exposure carries a potential stochastic effect (cfr. the LNT model, earlier described in this article) and what is even more disturbing is the fact that the severity of the effect is not related to the radiation dose (Hendee et al. 2002; Graham et al. 2004; Whaites 2007a; Mettler and Upton 2008).

Cone beam CT in paediatric dentistry

All of the above puts cone beam CT (CBCT) with regard to paediatric dentistry in a different perspective. Obviously there is no need for specific CBCT guidelines, as the three basic principles of radiation protection can still be applied to assess the need for a CBCT examination in a particular situation. The individual based approach makes more sense than a table listing indications for CBCT, and focuses on fields of view sizes and image resolution in paediatric dentistry. Studies stress that justification to expose the patient to a higher effective dose than with conventional peri-apical radiographs, still needs to be assessed. Secondary to this, optimisation should be addressed as any radiation dose should always be kept as low as reasonably achievable (Farman 2005; Haiter-Neto et al. 2008; Patel and Horner 2009; Koong 2010; Katheria et al. 2010; Patel et al. 2011; Davies et al. 2012; Hassan et al. 2012; Pauwels et al. 2012; Scarfe et al. 2012).

Clinical aspects of using CBCT

Effective dose

The field of view and the spatial resolution of any scan may have a substantial influence on the effective dose. Increasing the voxel size accuracy of the scan from 400 to 200 μm doubles the effective dose because twice as many projections have to be made. Great discrepancy between figures mentioned by different investigations can be attributed to different calculation methods and the use of different brands of CBCT machines (different field of view, kilovoltage and milli-Ampère settings). Despite the fact that CBCT effective doses are considerably lower than the doses from multislice CT, they are still very much higher

than those generated by the usual conventional dental radiographic exposures. The difference between the effective dose from a panoramic radiograph exposure and the effective dose from a CBCT exposure can be a factor of 5–16!

Risk

The ICRP suggests a nominal probability coefficient for all radiation induced fatal cancers averaged over a whole population to be 5 % per Sievert, which consequently renders the risk associated with CBCT to be between 1 in 100,000 and 1 in 350,000. They emphasise that this is the risk for an adult patient and that the risk should obviously not be ignored at all when dealing with children (Roberts et al. 2009). Theodorakou et al. (2012) investigated the doses from five different CBCT machines for a 10-year-old child and an adolescent person. They found that the doses were equal to those in adults. The thyroid gland seemed to receive four times more radiation in a 10-year-old than in an adolescent because of the anatomy of the patient. The investigators also mentioned that the risks for children are considerably higher than for adults and they emphasised the importance of justification for this level of exposures and for dose optimisation, which can be obtained by using the correct collimation. Differences in effective dose between CBCT machines have also been reported and were obviously related to field of view, resolution, and exposure parameters (kV and mA).

Radiation protection devices

An interesting study was published (Qu et al. 2012) on the use of a thyroid-protecting collar for CBCT imaging, in which it was demonstrated that the correct use of such a collar, during CBCT imaging, can reduce the dose to the thyroid gland and the oesophagus by approximately 50 and 40 % respectively. However, the total effective dose to the patient did not change. The latter means only localised effective dose reduction can be achieved with the use of lead shielding. The possibility of using lead goggles has also been mentioned in order to reduce the dose to the eye during CBCT imaging, as exposure to ionizing radiation can certainly lead to opacification (cataract) and resultant impaired vision. Due to the inter-individual susceptibility differences to ionizing radiation and the fact that children especially have to be protected more from ionizing radiation, radiation protection should always be considered. Lead glasses worn by the (paediatric) patient proved effective and was able to reduce the dose by 67 %, although this can, of course, only be performed if the field of interest involves the orbita (Prins et al. 2011).

Ludlow (2011) emphasised that radiation protection is of utmost importance in children, especially because of the extensive increase in the number of radiographic examinations undertaken. This study stressed the important role manufacturers can play in collaborating with practitioners and clinicians to reduce the radiation dose without compromising the image quality.

CBCT usage

De Vos et al. (2009) have compiled a list of papers on the use of CBCT in different fields of dentistry. The majority of CBCT use was observed in maxillofacial surgery (41 %), followed by dento-alveolar issues (29 %), orthodontics (16 %) and dental implantology (11 %). Endodontology, periodontology, general dentistry and forensic dentistry made up for the remaining 9 %, while only 1 % of papers concerned the use of CBCT in otolaryngology.

The main advantage of CBCT is that it offers a real-size dataset with multiplanar cross-sectional (axial, sagittal and coronal planes) and three-dimensional reconstructions, resulting from a single scan. The latter means a much lower effective dose to a patient in comparison to multislice (medical) CT. The main disadvantage is that Hounsfield Units (HU), which are available in CT investigations, cannot be derived and that there is only very limited soft tissue differentiation possible (Ahmad et al. 2012), making it unsuitable as a single imaging tool in skull trauma with possible brain damage (De Vos et al. 2009). Those authors also express their concern that CBCT is mainly purchased by general dental practitioners or maxillofacial surgeons, unlike medical imaging, where three dimensional imaging equipment, such as MSCT (multislice CT) is only handled by radiology specialists. They attribute the sometimes erroneous results in the literature to the fact that CBCT users are not always aware of the technical aspects of the equipment they are using, which one day might lead to medico-legal consequences. It is certain that CBCT will improve patient care, but practitioners need to be properly educated when working with this kind of equipment. Users need to be capable of reading and interpreting the whole scanned volume as is strongly advised by the author of this review paper. Besides, medico-legal liability will certainly play an important role in the future, as these three-dimensional datasets contain considerable amounts of information beyond the area of interest (Koong 2010).

Calcified tissues

An overview of potential uses of CBCT in the maxillofacial region published in 2012, mentions that CBCT has a place in diagnosing calcified tissues, but that its use to investigate soft tissues should be avoided at all times. The

lower radiation dose compared with MSCT can be a reason to prefer CBCT technique over MSCT, especially in a follow-up of pathology or trauma of the hard tissues (Ahmad et al. 2012). Similar comments with regard of the use of CBCT to investigate the TMJ emphasise that CBCT should only be used when it concerns issues with the hard tissues of the joint or as an adjunct to MRI, as with the latter, osseous changes can sometimes not be assessed correctly. Many soft tissue changes have an effect on the osseous contours of the condyle and therefore CBCT might be a welcome diagnostic tool, as it causes a lower radiation dose to the patient than MSCT (Alkhader et al. 2010).

Surgical planning

Cone beam computed tomography measurements are also accurate enough to be used for surgical planning (Sakabe et al. 2007). Besides surgery for implants unerupted teeth intended to be used for autotransplantation can be measured prior to extraction to prepare for the surgery and to prepare the implant bed.

CBCT artefacts

The CBCT technique is however also very prone to artefacts, caused by patient movement or by metallic inclusions, implants, amalgam fillings and endodontic obturation materials. Several manufacturers have altered algorithms to take care of the image quality issues caused by high attenuating materials, however they are still not able to get rid of all artefacts and certainly not of any movement caused artefacts. Figure 1 shows some illustrations of hard to interpret artefacts due to the presence of very radiopaque materials. So-called streaking artefacts (caused by beam hardening—explaining this is beyond the scope of this review) will deteriorate the image quality and impede the diagnostic value of the image. Knowing that artefacts like this will appear on the CBCT image should make the practitioner reconsider the exposure.

Spin-Neto et al. (2012) mention the issue of patient motion artefacts, which causes the images to become blurry and therefore to be unfit for diagnostic purposes. Patient movement involves breathing, heartbeat, muscular movements and tremor. When artefacts occur the image will be blurry, show stripe- or ring-like artefacts, and double contours. For all currently available CBCT units any patient movement will result in a geometric error in the reconstruction process, which in its turn will lead to low qualitative images (Spin-Neto et al. 2012). Figure 2 shows an example of motion artefact on CBCT. The mandible appears to be fractured at the midline, and in the sagittal image it seems as if a parallel shadow of the mandible has occurred. The lower images are obtained from a 9 year-old

child, who was unable to sit still enough during the 20 s rotation time (effective exposure was less due to the stroboscopic or intermittent X-ray beam).

Donaldson et al. (2012) investigated the relationship between motion artefacts in CBCT images, causing a lack of sharpness or double contours of bony margins, and a patient's age. They found that only 0.5 % of images they had randomly selected from their database needed to be retaken for motion artefacts. The subjects involved were either younger than 16 or older than 65 years old. They re-evaluated their database and found that in the youngest age group, motion artefacts occurred in 10.7 % and of those 86 % were in males. In the older age group (over 65 years old), the prevalence of motion artefacts was 21.6 %, with 62.5 % of them being females. The latter group had other health issues, explaining the cause of the motion artefact (Donaldson et al. 2012). It is important to avoid motion artefacts, especially in children, to avoid having to retake CBCT assessments and hence a higher radiation dose (Hanzelka et al. 2010).

Orthodontics

In some orthodontic reports, the focus has been on recognition of so-called orthodontic landmarks through CBCT, compared with classical cephalometric two-dimensional imaging. The conclusion is that two-dimensional is still the preferred method and that CBCT should only be used in very distinctive, well-selected and justified cases. CBCT in children should be used with caution, as exposing children to ionizing radiation should be kept as low as possible (Kumar et al. 2007; Alves Garcia Silva et al. 2008; Delamare et al. 2010; Jacquet et al. 2010; Mah et al. 2011). In contrast, Nervina (2012) reviewed the literature regarding orthodontics and CBCT and only found three studies that were not able to show a superiority of CBCT over 2D cephalometric imaging. That author had only addressed the technical advantages of CBCT images, such as the three dimensional information that could be obtained, the possibility to measure structures without having to use conversion factors, and the fact that a large field of view CBCT scan can replace alginate impressions. This author even mentions the possibility to use CBCT for orthodontic treatment follow-up to assess changes in bone thickness or dental position! The author of the present review would like to emphasise that the latter is disturbing and should not be considered as a standard.

The prevalence of incidental findings on CBCT images in orthodontic patients was also investigated and concluded that in almost 25 % of cases, one of the following incidental significant findings could be recorded: airway issues, temporomandibular joint issues, endodontic issues and maxillary sinus pathology. Ironically the British Orthodontic

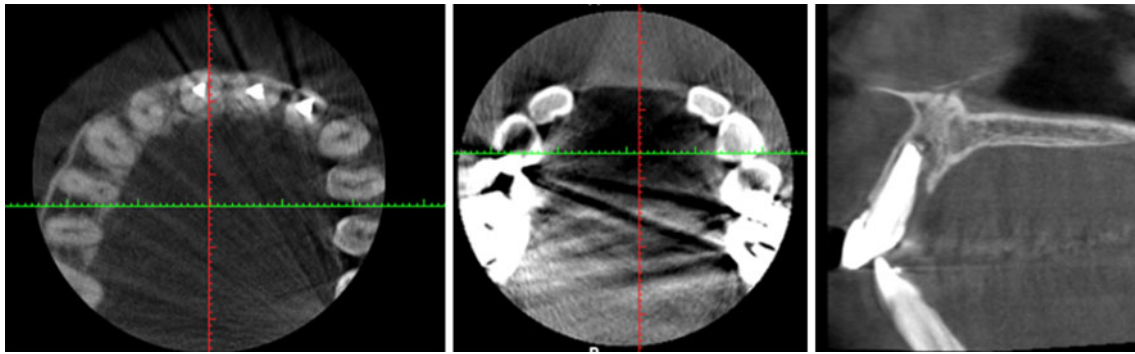


Fig. 1 Example of some artefacts on CBCT caused by highly radiopaque materials: *left* and *middle* are axial images where the streaking artefacts are very explicit—*right* is a sagittal image where

the endodontic material obscures the area immediately around it, making diagnosis of potential fractures impossible

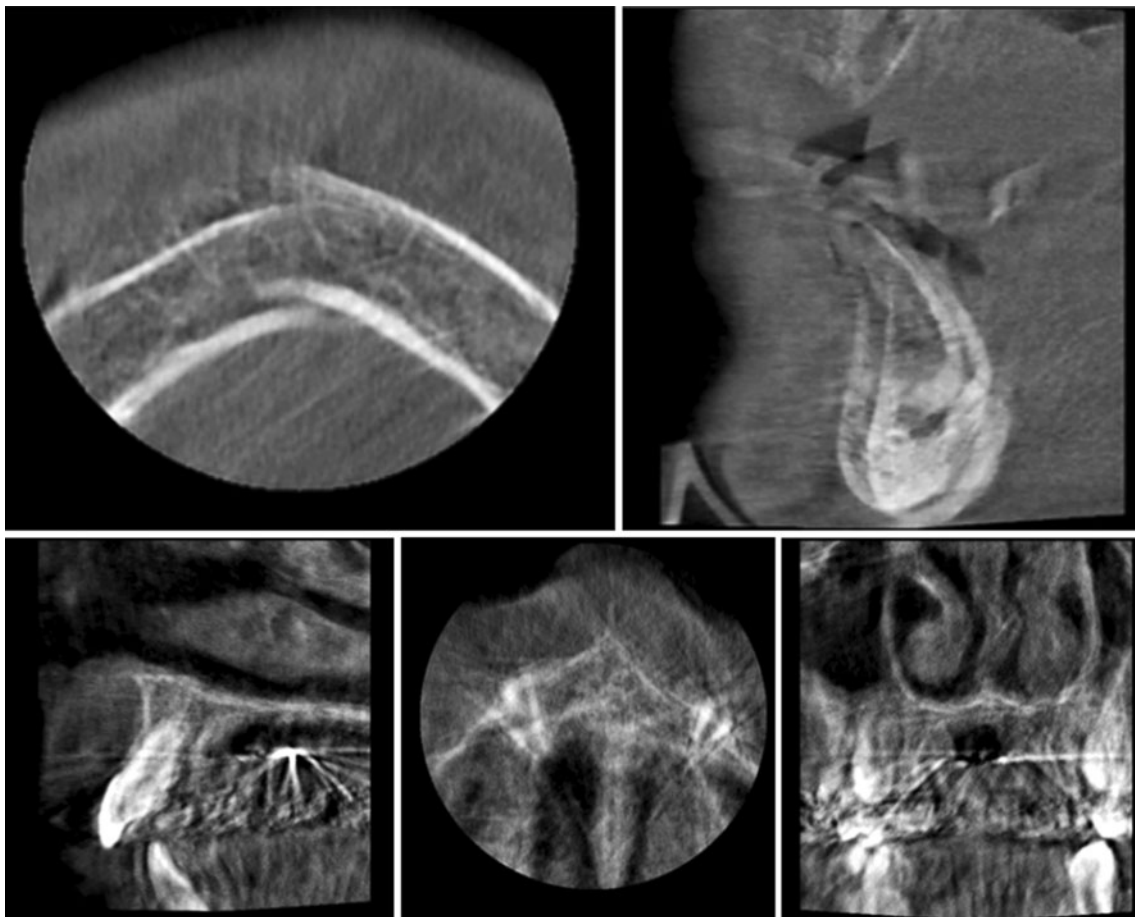


Fig. 2 Example of a motion artefact on CBCT. *Image* on the *left* is the axial plane and *image* on the *right* is the sagittal plane. *Bottom images* show a combination of motion artefact and metal

Society has published guidelines on the use of radiographs in orthodontic patients (Isaacson et al. 2008), and concluded that routine use of CBCT radiographs is not appropriate. It is, however, disturbing that Dr Nervina does not discuss radiation safety and radiation protection issues, especially because the majority of orthodontic patients are children

and adolescents. In the summary, Dr. Nervina (2012), uses the excuse of missing USA guidelines for the use of CBCT in orthodontic patients.

So called “complex craniofacial and surgical cases and cases of missing or impacted teeth” may be the most suitable candidates for CBCT imaging, although the

absolute need for CBCT imaging must be determined on a “case-by-case basis”. Dr Nervina mentions in the next sentence “CBCT imaging provides orthodontists with an excellent tool to improve diagnosis, treatment planning and outcomes assessment in appropriate malocclusion cases”. The latter shows the lack of interest and criticism in patient radiation dose reduction and radiation protection, as the outcome of an orthodontic treatment should a priori not be assessed by means of ionizing radiation! Similar study conclusions were also found in a review article published in 2011 by Kapila et al. (2011).

It is peculiar that another review in 2012 by van Vlijmen et al. concluded that “there is no high-quality evidence regarding the benefits of CBCT use in orthodontics”. These authors emphasised that the benefit for a patient should always be weighed against the risk of developing a fatal cancer due to ionizing radiation exposure, and concluded that this risk has not yet been proven in the literature. Moreover, those authors mention the lack of radiation protection and justification for the use of ionizing radiation in many of the orthodontic papers dealing with the use of radiology in orthodontic and suggest that future studies focus on the effects of using CBCT on orthodontic treatment procedures, orthodontic treatment progression and the outcome of the treatment in a quantitative manner (van Vlijmen et al. 2012).

Root treatments

Wang et al. (2011a) studied in vivo results of endodontically treated teeth with suspected root fractures. While the endodontic filling material impaired the detection of root fractures, CBCT still performed better than plain radiographs in detecting root fractures. It needs to be mentioned that 70 % of the teeth involved in this study did not have a root canal treatment, which may explain the results. Presence of root canal filling material and metallic posts causes star-like streaking artefacts, which may impair assessment of root fractures (Wang et al. 2011a). Dalili Kajan and Taromsari (2012) performed an in vivo study on 10 patients, all with endodontically treated teeth and clinical symptoms of root fractures. They diagnosed the CBCT images prior to tooth extraction, which served as a ‘gold standard’. Despite their enthusiasm about the use of CBCT to detect root fractures, the authors mention the issue of the radiation dose and the importance of a good clinical examination, which lies at the basis of treatment decisions and justification of additional use of ionizing radiation (Dalili Kajan and Taromsari 2012). Kambungton et al. (2012) completed an in vitro study to assess the difference in accuracy of detecting vertical root fractures between CBCT (Veraview Epos[®]), intra-oral digital radiography (CMOS) and analogue (F-speed) film. Their conclusion was that there was

no significant difference between these three modalities, despite CBCT scoring better over the entire line. The latter is supported by an earlier study by Wang et al. (2011b) who stressed the fact that CBCT should only be used if justified, with regard to the radiation dose.

Dental caries detection

In an in vitro study comparing 2 CBCT units (New Tom 3G[®] and 3DX Accuitomo[®]), one analogue film (Kodak Insight[®]) and a storage phosphor plate system (Digora[®]) on their ability to detect interproximal and occlusal caries, the Accuitomo[®] scored best, but similar to analogue film or storage phosphor plate (Haiter-Neto et al. 2008). The authors emphasise that the effective radiation dose for intra-oral imaging varies between 1 and 8 μSv , whereas the effective dose for CBCT will be considerably higher. They stress that, especially in paediatric patients, radiation dose should be kept as low as possible and any exposure justified. The use of CBCT cannot be justified for caries diagnostics (Haiter-Neto et al. 2008). The latter can, however, be an incidental finding in a CBCT volume of data. Young et al. (2009) performed a similar in vitro study, also using the 3DX Accuitomo[®] and compared it with a Gendex[®] solid state sensor with respect to the detection of dental caries. Examiners were able to detect interproximal lesions into dentine with the CBCT images. With regard to interproximal enamel lesions, CBCT and solid-state sensor both scored low in true scores. For occlusal caries scores it was observed that CBCT gave more false positive cases. It was mentioned that dentine sometimes showed less radiopaque areas on CBCT images, rendering the image subject to false positive ratings. Apparently these false radiolucent areas may be due to exposure geometry, as dentine under cusps will attenuate less X-rays than dentine in the rest of the body of the crowns of the teeth. This effect could be avoided when individual teeth were imaged.

The effective radiation dose of 20 microSievert to which patients are exposed when undergoing a 40×40 mm CBCT scan with the Accuitomo[®] is significantly different compared with four bitewing radiographs taken with a rectangular collimator (5 microSievert). Caries diagnostics can be performed to a certain extent, when assessing CBCT images, which were made for other purposes. They should obviously never be made for caries diagnostic purposes (Young et al. 2009; Wenzel et al. 2013).

Conclusions

The indications for the use of CBCT in paediatric dentistry have not as yet been properly addressed, but the three basic principles of radiation protection should suffice for the use

of CBCT in children. CBCT certainly has place in paediatric dentistry, but its use must be justified on a patient case individual basis, where benefits must clearly outweigh the potential risks. The effective radiation dose should not be underestimated, especially in children, who are much more susceptible to stochastic biological effects. The thyroid gland in particular should be kept out of the primary beam as much as possible. As with any other radiographical technique, routine use of CBCT is not acceptable clinical practice.

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